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Ganzel

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(54) **VEHICLE BRAKE SYSTEM WITH DUAL ACTING PLUNGER ASSEMBLY**

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B60T 7/04 (2006.01)
B60T 8/40 (2006.01)

(52) **U.S. Cl.**

CPC ***B60T 13/168*** (2013.01); ***B60T 7/042*** (2013.01); ***B60T 8/4081*** (2013.01); ***B60T 13/166*** (2013.01); ***B60T 13/745*** (2013.01); *B60T 8/4018* (2013.01)

(58) **Field of Classification Search**

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USPC 60/545

See application file for complete search history.

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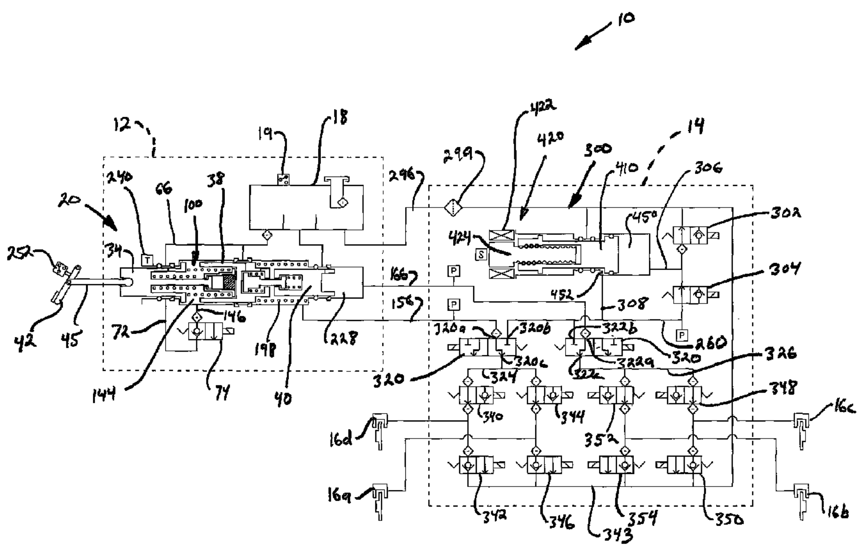
(57) **ABSTRACT**

A plunger assembly for use as a pressure source for a brake system includes a housing having first and second ports. A motor is mounted on the housing for driving an actuator. A piston is connected to the actuator. The piston is slidably mounted within the housing. The piston pressurizes a first chamber when the piston is moving in a first direction to provide fluid out of the first port. The piston pressurizes a second chamber when the piston is moving in a second direction to provide fluid out of the second port.

8 Claims, 8 Drawing Sheets



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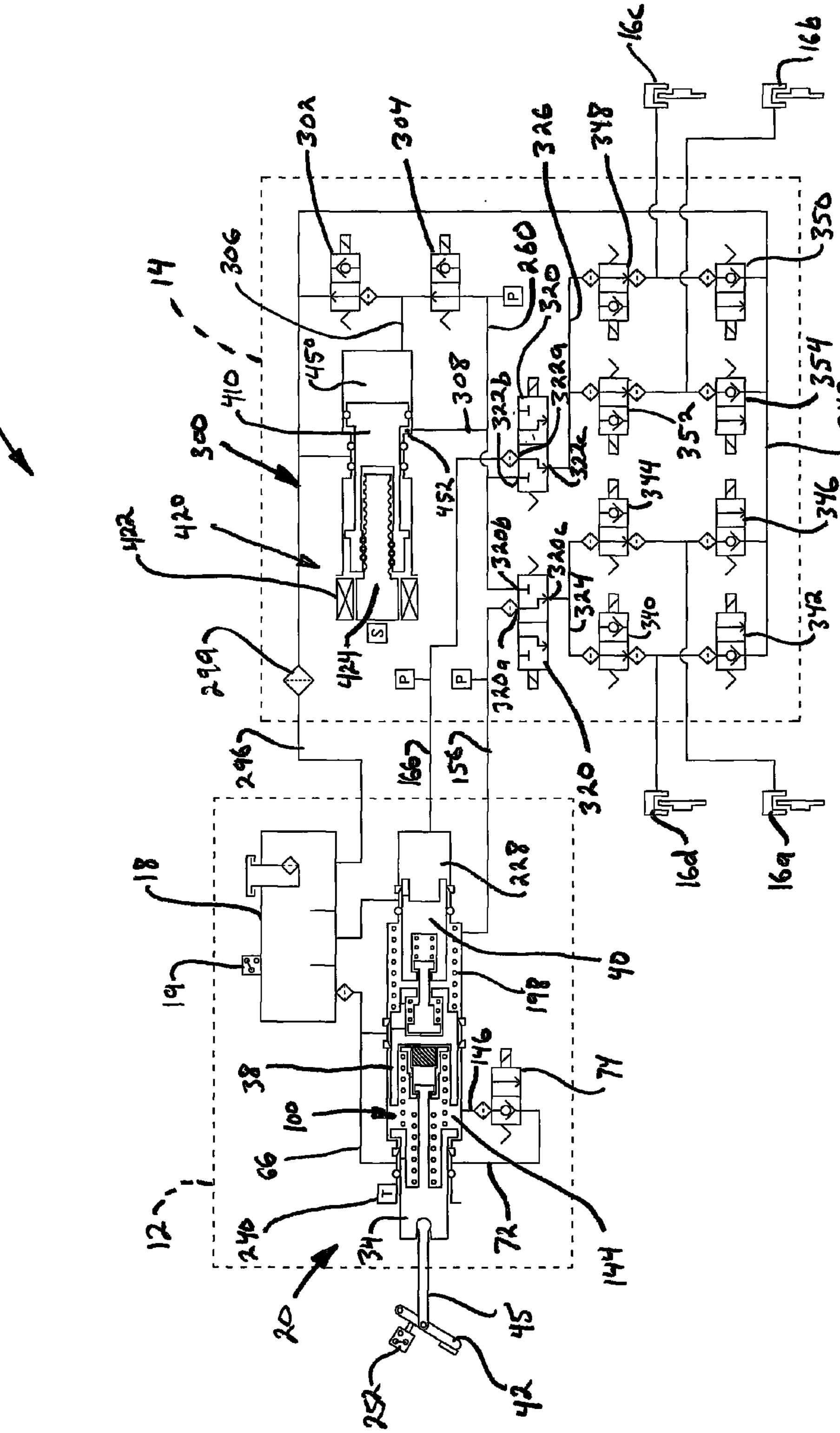

Fig. 1

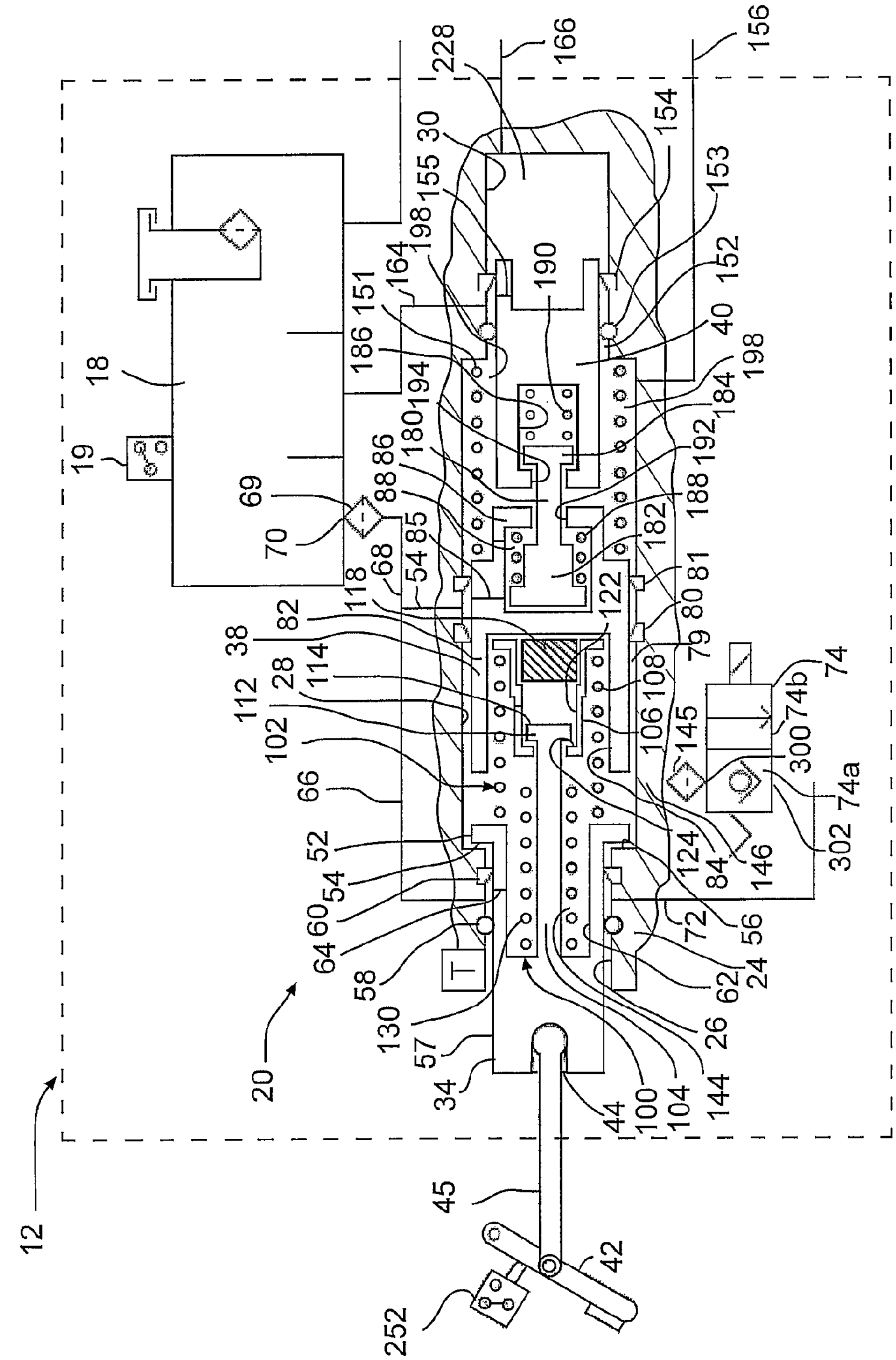
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FIG. 2

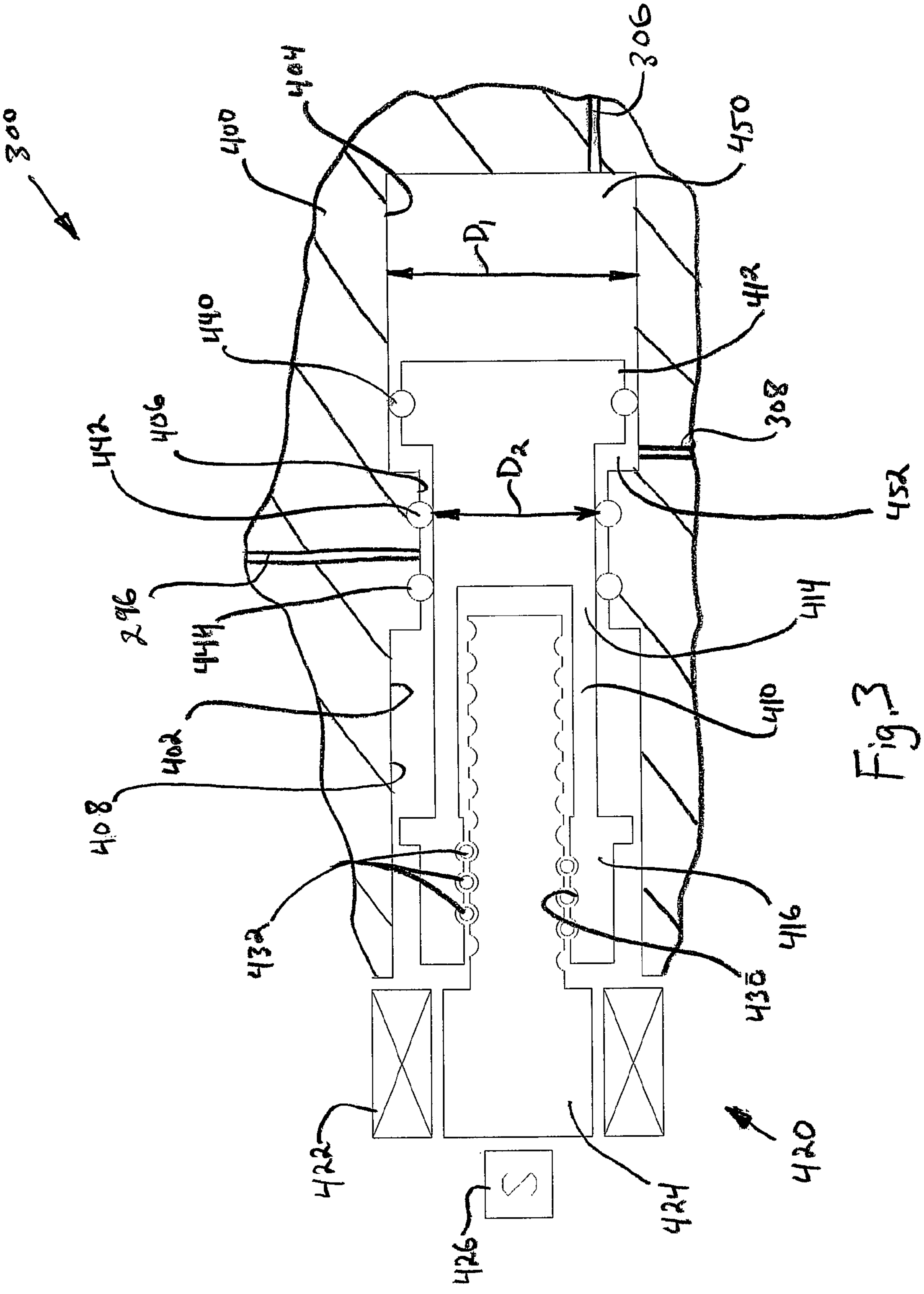
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Fig. 3

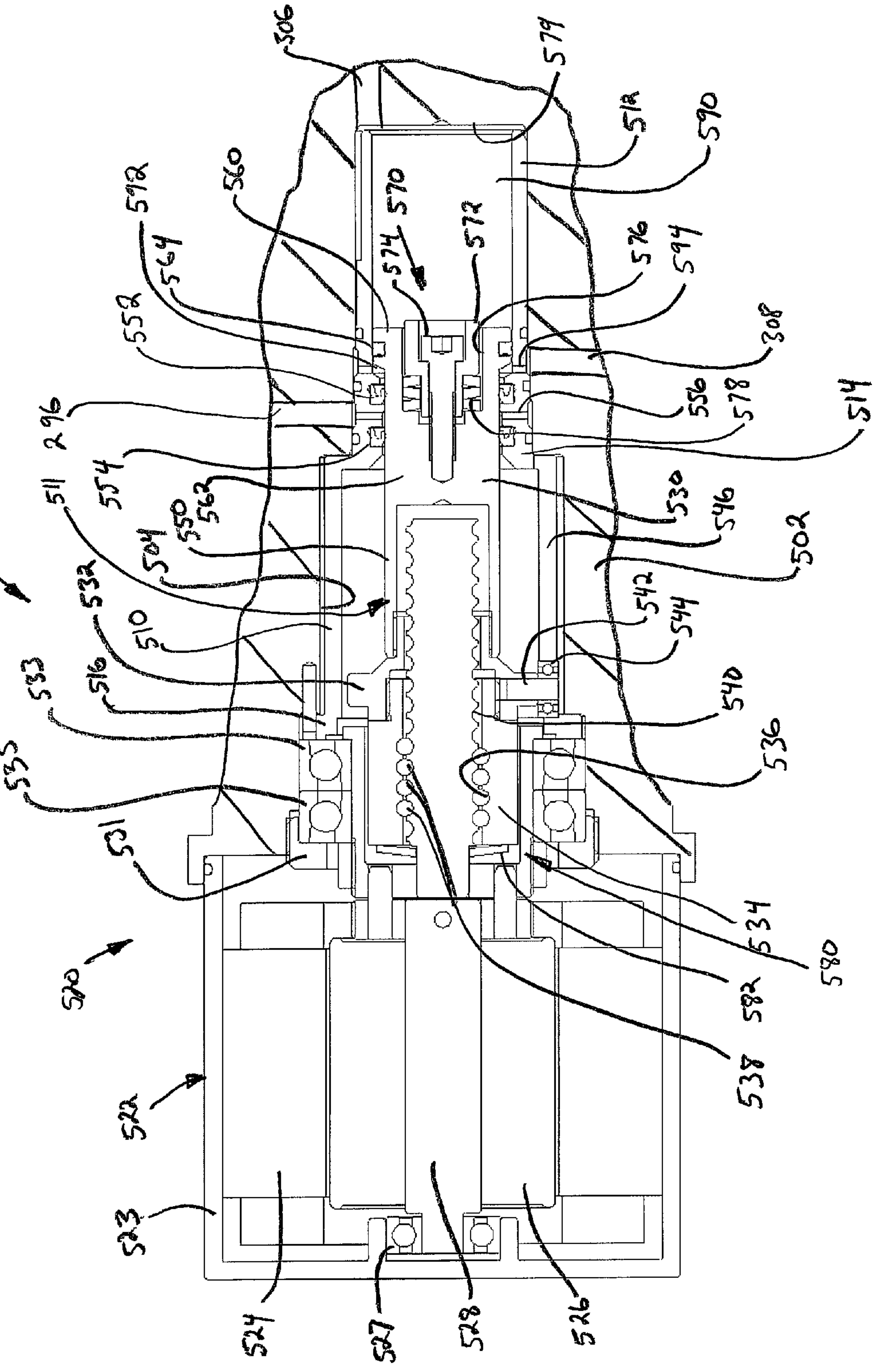
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Fig. 4

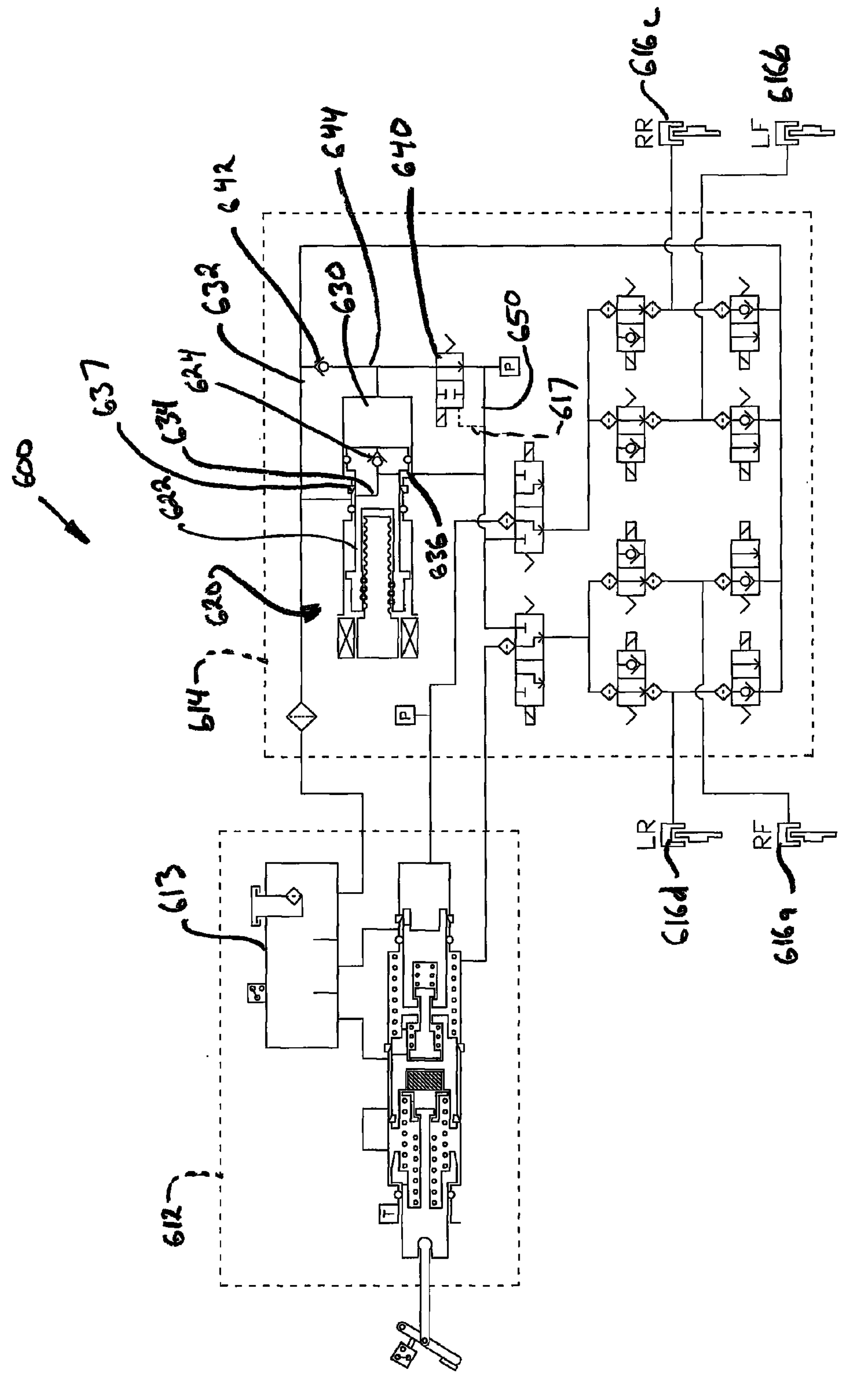
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Fig. 5

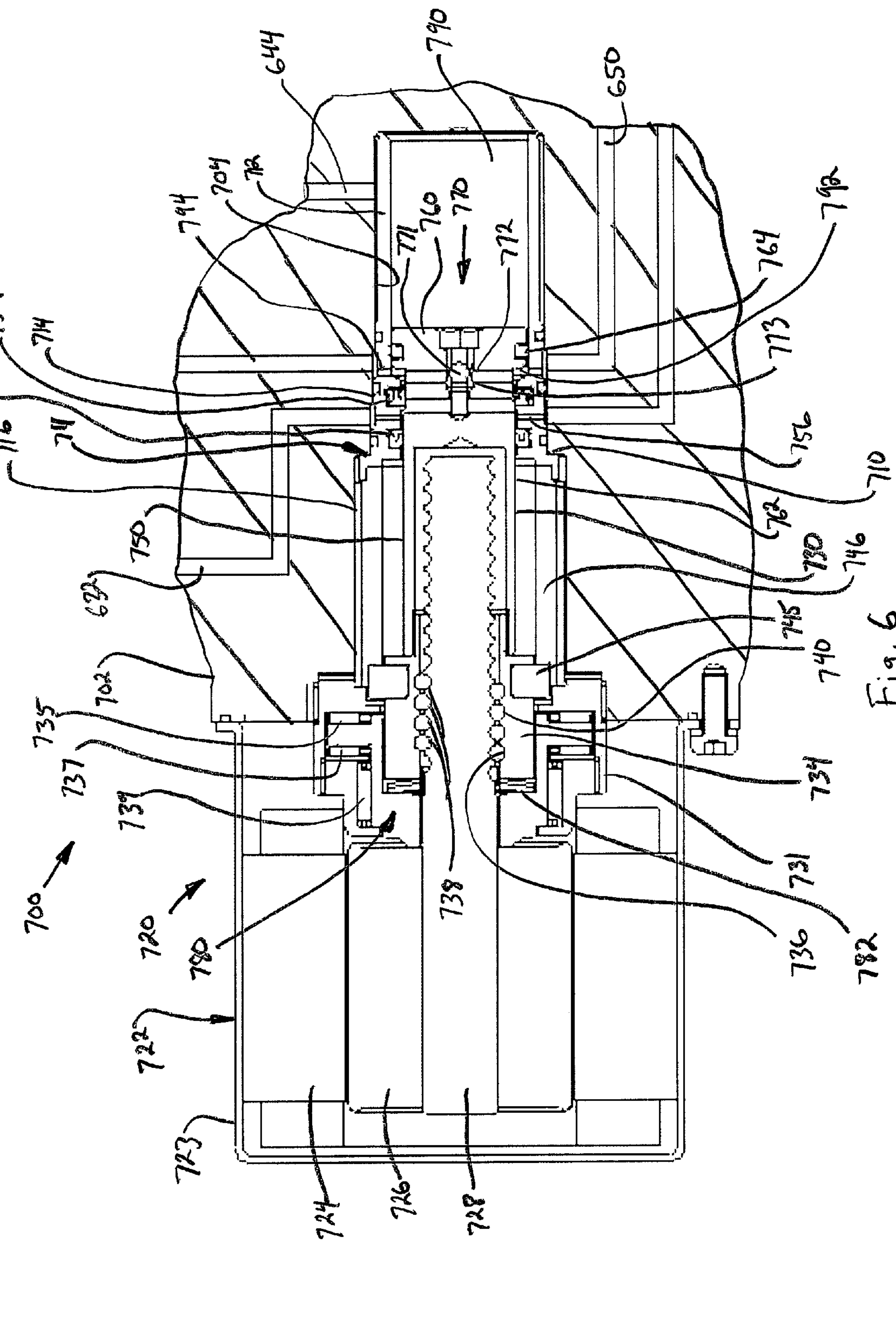

Fig. 6

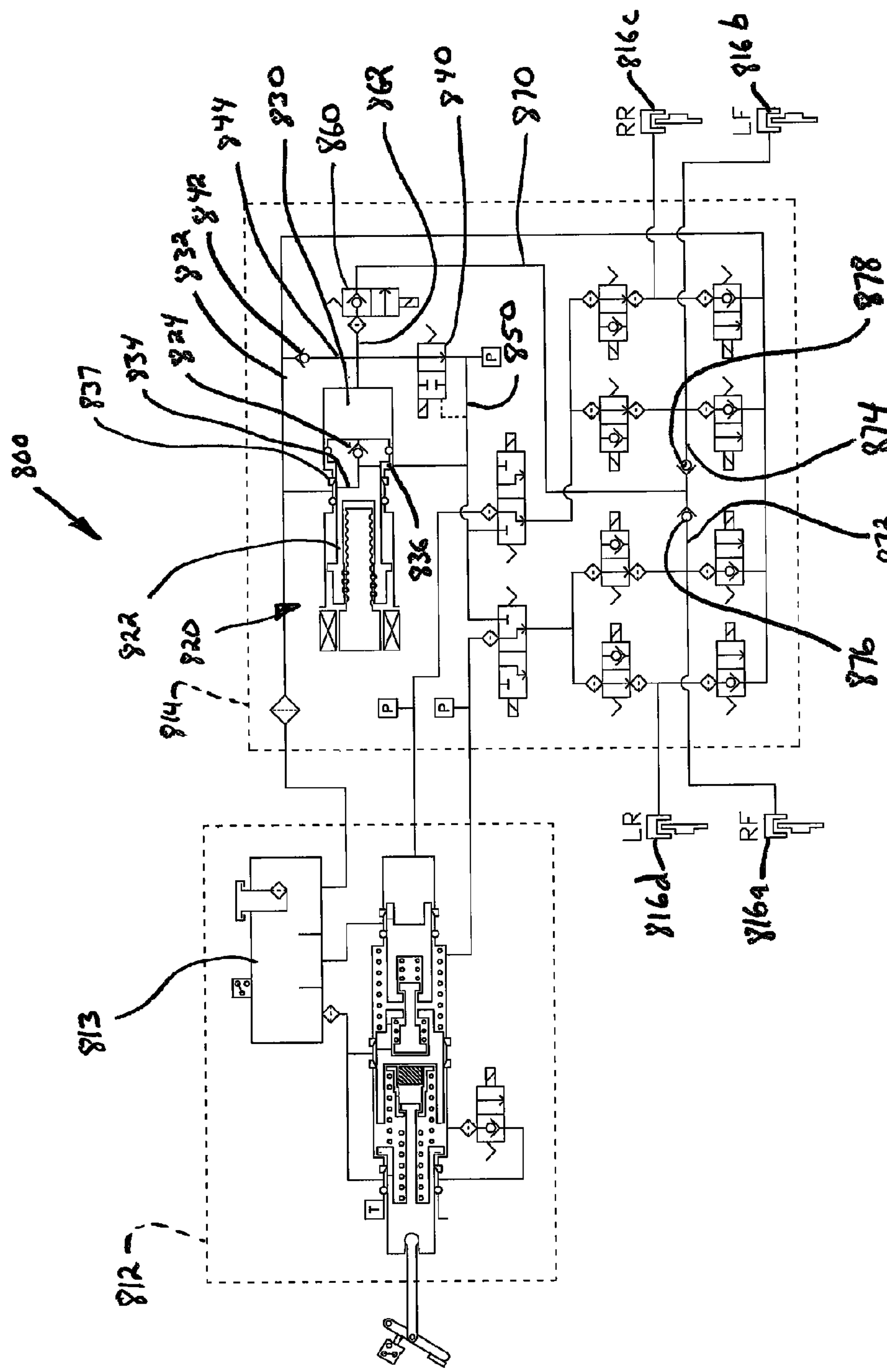
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Fig. 7

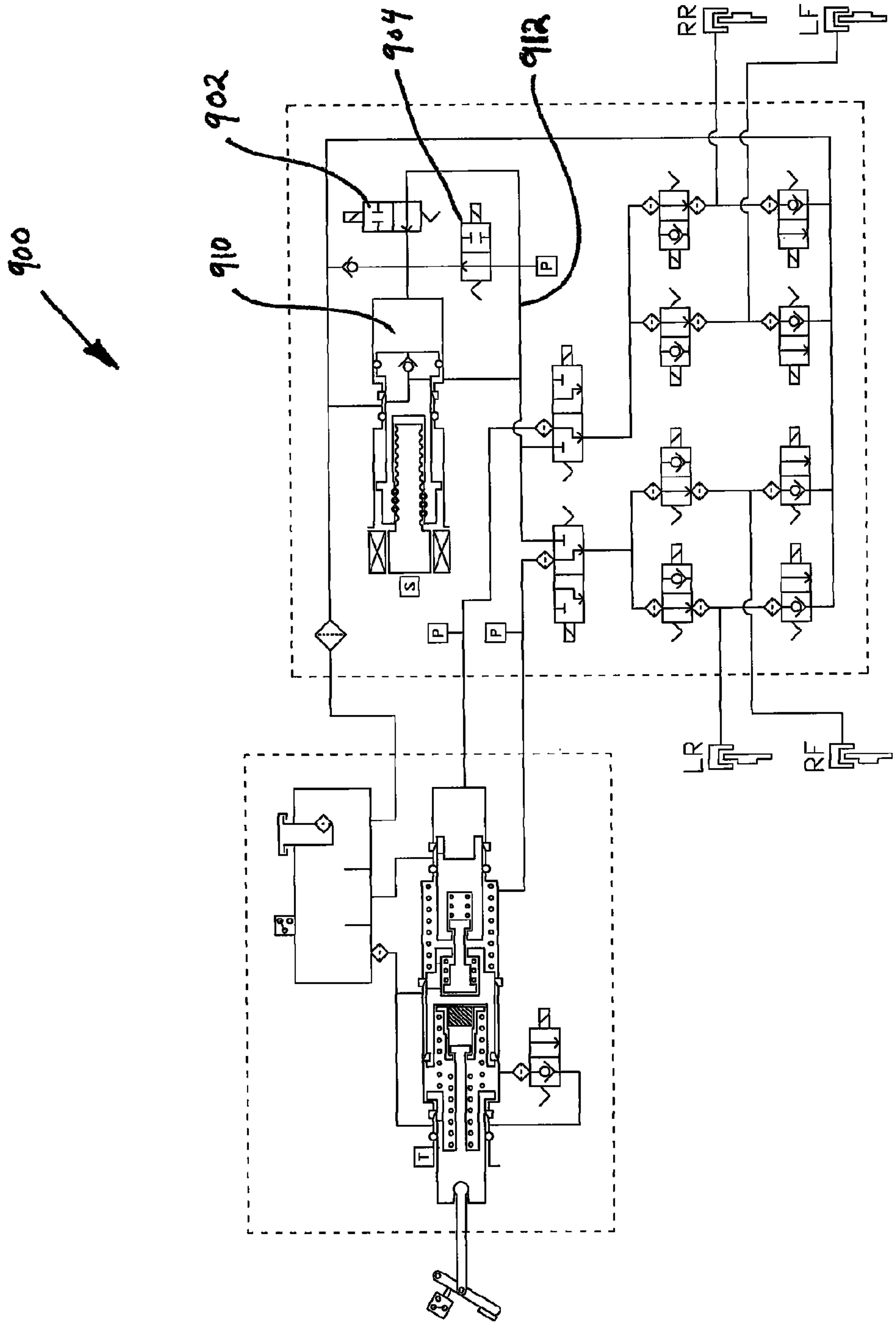

Fig. 8

VEHICLE BRAKE SYSTEM WITH DUAL ACTING PLUNGER ASSEMBLY

BACKGROUND OF THE INVENTION

This invention relates in general to vehicle braking systems. Vehicles are commonly slowed and stopped with hydraulic brake systems. These systems vary in complexity but a base brake system typically includes a brake pedal, a tandem master cylinder, fluid conduits arranged in two similar but separate brake circuits, and wheel brakes in each circuit. The driver of the vehicle operates a brake pedal which is connected to the master cylinder. When the brake pedal is depressed, the master cylinder generates hydraulic forces in both brake circuits by pressurizing brake fluid. The pressurized fluid travels through the fluid conduit in both circuits to actuate brake cylinders at the wheels to slow the vehicle.

Base brake systems typically use a brake booster which provides a force to the master cylinder which assists the pedal force created by the driver. The booster can be vacuum or hydraulically operated. A typical hydraulic booster senses the movement of the brake pedal and generates pressurized fluid which is introduced into the master cylinder. The fluid from the booster assists the pedal force acting on the pistons of the master cylinder which generate pressurized fluid in the conduit in fluid communication with the wheel brakes. Thus, the pressures generated by the master cylinder are increased. Hydraulic boosters are commonly located adjacent the master cylinder piston and use a boost valve to control the pressurized fluid applied to the booster.

Braking a vehicle in a controlled manner under adverse conditions requires precise application of the brakes by the driver. Under these conditions, a driver can easily apply excessive braking pressure thus causing one or more wheels to lock, resulting in excessive slippage between the wheel and road surface. Such wheel lock-up conditions can lead to greater stopping distances and possible loss of directional control.

Advances in braking technology have led to the introduction of Anti-lock Braking Systems (ABS). An ABS system monitors wheel rotational behavior and selectively applies and relieves brake pressure in the corresponding wheel brakes in order to maintain the wheel speed within a selected slip range to achieve maximum braking force. While such systems are typically adapted to control the braking of each braked wheel of the vehicle, some systems have been developed for controlling the braking of only a portion of the plurality of braked wheels.

Electronically controlled ABS valves, comprising apply valves and dump valves, are located between the master cylinder and the wheel brakes. The ABS valves regulate the pressure between the master cylinder and the wheel brakes. Typically, when activated, these ABS valves operate in three pressure control modes: pressure apply, pressure dump and pressure hold. The apply valves allow pressurized brake fluid into respective ones of the wheel brakes to increase pressure during the apply mode, and the dump valves relieve brake fluid from their associated wheel brakes during the dump mode. Wheel brake pressure is held constant during the hold mode by closing both the apply valves and the dump valves.

To achieve maximum braking forces while maintaining vehicle stability, it is desirable to achieve optimum slip levels at the wheels of both the front and rear axles. During vehicle deceleration different braking forces are required at the front and rear axles to reach the desired slip levels. Therefore, the brake pressures should be proportioned between the front and rear brakes to achieve the highest braking forces at each axle. ABS systems with such ability, known as Dynamic Rear Proportioning (DRP) systems, use the ABS valves to separately control the braking pressures on the front and rear wheels to dynamically achieve optimum braking performance at the front and rear axles under the then current conditions.

A further development in braking technology has led to the introduction of Traction Control (TC) systems. Typically, valves have been added to existing ABS systems to provide a brake system which controls wheel speed during acceleration. Excessive wheel speed during vehicle acceleration leads to wheel slippage and a loss of traction. An electronic control system senses this condition and automatically applies braking pressure to the wheel cylinders of the slipping wheel to reduce the slippage and increase the traction available. In order to achieve optimal vehicle acceleration, pressurized brake fluid is made available to the wheel cylinders even if the master cylinder is not actuated by the driver.

During vehicle motion such as cornering, dynamic forces are generated which can reduce vehicle stability. A Vehicle Stability Control (VSC) brake system improves the stability of the vehicle by counteracting these forces through selective brake actuation. These forces and other vehicle parameters are detected by sensors which signal an electronic control unit. The electronic control unit automatically operates pressure control devices to regulate the amount of hydraulic pressure applied to specific individual wheel brakes. In order to achieve optimal vehicle stability, braking pressures greater than the master cylinder pressure must quickly be available at all times.

Brake systems may also be used for regenerative braking to recapture energy. An electromagnetic force of an electric motor/generator is used in regenerative braking for providing a portion of the braking torque to the vehicle to meet the braking needs of the vehicle. A control module in the brake system communicates with a powertrain control module to provide coordinated braking during regenerative braking as well as braking for wheel lock and skid conditions. For example, as the operator of the vehicle begins to brake during regenerative braking, electromagnet energy of the motor/generator will be used to apply braking torque (i.e., electromagnetic resistance for providing torque to the powertrain) to the vehicle. If it is determined that there is no longer a sufficient amount of storage means to store energy recovered from the regenerative braking or if the regenerative braking cannot meet the demands of the operator, hydraulic braking will be activated to complete all or part of the braking action demanded by the operator. Preferably, the hydraulic braking operates in a regenerative brake blending manner so that the blending is effectively and unnoticeably picked up where the electromagnetic braking left off. It is desired that the vehicle movement should have a smooth transitional change to the hydraulic braking such that the changeover goes unnoticed by the driver of the vehicle.

Some braking systems are configured such that the pressures at each of the wheel brakes can be controlled independently (referred to as a multiplexing operation) from one another even though the brake system may includes a single source of pressure. Thus, valves downstream of the pressure source are controlled between their open and closed positions to provide different braking pressures within the wheel brakes. Such multiplex systems, which are all incorporated by reference herein, are disclosed in U.S. Pat. No. 8,038,229, U.S. Patent Application Publication No. 2010/0026083, U.S.

Patent Application Publication No. 2012/0013173, and U.S. Patent Application Publication No. 2012/0306261.

SUMMARY OF THE INVENTION

This invention relates to a plunger assembly for use as a pressure source for a vehicle brake system. The plunger assembly includes a housing having first and second ports. A motor is mounted on the housing for driving an actuator. A piston is connected to the actuator. The piston is slidably mounted within the housing. The piston pressurizes a first chamber when the piston is moving in a first direction to provide fluid out of the first port. The piston pressurizes a second chamber when the piston is moving in a second direction to provide fluid out of the second port.

Various aspects of this invention will become apparent to those skilled in the art from the following detailed description of the preferred embodiment, when read in light of the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic illustration of a first embodiment of a brake system.

FIG. **2** is an enlarged schematic sectional view of the brake pedal unit assembly of the brake system of FIG. **1** shown in its rest position.

FIG. **3** is an enlarged schematic sectional view of the plunger assembly of the brake system of FIG. **1** shown in a rest position.

FIG. **4** is an alternate embodiment of a plunger assembly which may be used in the brake system of FIG. **1**.

FIG. **5** is a schematic illustration of a second embodiment of a brake system.

FIG. **6** is an alternate embodiment of a plunger assembly which may be used in the brake system of FIG. **5**.

FIG. **7** is a schematic illustration of a third embodiment of a brake system.

FIG. **8** is a schematic illustration of a fourth embodiment of a brake system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings, there is schematically illustrated in FIG. **1** a first embodiment of a vehicle brake system, indicated generally at **10**. The brake system **10** is a hydraulic boost braking system in which boosted fluid pressure is utilized to apply braking forces for the brake system **10**. The brake system **10** may suitably be used on a ground vehicle such as an automotive vehicle having four wheels with a wheel brake associated with each wheel. Furthermore, the brake system **10** can be provided with other braking functions such as anti-lock braking (ABS) and other slip control features to effectively brake the vehicle, as will be discussed below.

The brake system **10** generally includes a first block or brake pedal unit assembly, indicated by broken lines **12**, and a second block or hydraulic control unit, indicated by broken lines **14**. The various components of the brake system **10** are housed in the brake pedal unit assembly **12** and the hydraulic control unit **14**. The brake pedal unit assembly **12** and the hydraulic control unit **14** may include one or more blocks or housings made from a solid material, such as aluminum, that has been drilled, machined, or otherwise formed to house the various components. Fluid conduits may also be formed in the housings to provide fluid passageways between the various components. The housings of the brake pedal unit assembly **12** and the hydraulic control unit **14** may be single structures or may be made of two or more parts assembled together. As schematically shown, the hydraulic control unit **14** is located remotely from the brake pedal unit assembly **12** with hydraulic lines hydraulically coupling the brake pedal unit assembly **12** and the hydraulic control unit **14**. Alternatively, the brake pedal unit assembly **12** and the hydraulic control unit **14** may be housed in a single housing. It should also be understood that the grouping of components as illustrated in FIG. **1** is not intended to be limiting and any number of components may be housed in either of the housings.

The brake pedal unit assembly **12** cooperatively acts with the hydraulic control unit **14** for actuating wheel brakes **16***a*, **16***b*, **16***c*, and **16***d*. The wheel brakes **16***a*, **16***b*, **16***c*, and **16***d* can be any suitable wheel brake structure operated by the application of pressurized brake fluid. The wheel brake **16***a*, **16***b*, **16***c*, and **16***d* may include, for example, a brake caliper mounted on the vehicle to engage a frictional element (such as a brake disc) that rotates with a vehicle wheel to effect braking of the associated vehicle wheel. The wheel brakes **16***a*, **16***b*, **16***c*, and **16***d* can be associated with any combination of front and rear wheels of the vehicle in which the brake system **10** is installed. For example, for a vertically split system, the wheel brakes **16***a* and **16***d* may be associated with the wheels on the same axle. For a diagonally split brake system, the wheel brakes **16***a* and **16***b* may be associated with the front wheel brakes.

The brake pedal unit assembly **12** includes a fluid reservoir **18** for storing and holding hydraulic fluid for the brake system **10**. The fluid within the reservoir **18** may be held generally at atmospheric pressure or can store the fluid at other pressures if so desired. The brake system **10** may include a fluid level sensor **19** for detecting the fluid level of the reservoir. The fluid level sensor **19** may be helpful in determining whether a leak has occurred in the system **10**.

The brake pedal control unit assembly **12** includes a brake pedal unit (BPU), indicated generally at **20**. The brake pedal unit **20** is also schematically shown enlarged in FIG. **2**. It should be understood that the structural details of the components of the brake pedal unit **20** illustrate only one example of a brake pedal unit **20**. The brake pedal unit **20** could be configured differently having different components than that shown in FIGS. **1** and **2**.

The brake pedal unit **20** includes a housing **24** (shown broken away in FIG. **2**) having various bores formed in for slidably receiving various cylindrical pistons and other components therein. The housing **24** may be formed as a single unit or include two or more separately formed portions coupled together. The housing **24** generally includes a first bore **26**, an intermediate second bore **28**, and a third bore **30**. The second bore **28** has a larger diameter than the first bore **26** and the third bore **30**. The brake pedal unit **20** further includes an input piston **34**, a primary piston **38**, and a secondary piston **40**. The input piston **34** is slidably disposed in the first bore **26**. The primary piston **38** is slidably disposed in the second bore **28**. The secondary piston **40** is slidably disposed in the third bore **30**.

A brake pedal, indicated schematically at **42** in FIGS. **1** and **2**, is coupled to a first end **44** of the input piston **34** via an input rod **45**. The input rod **45** can be coupled directly to the input piston **34** or can be indirectly connected through a coupler (not shown). The input piston **34** includes an enlarged second end **52** that defines a shoulder **54**. In the rest position shown in FIGS. **1** and **2**, the shoulder **54** of the input piston engages with a shoulder **56** formed between the first and second bores **26** and **28** of the housing **24**. An outer cylindrical surface **57** of the input piston **34** is engaged with a seal **58** and a lip seal **60** mounted in grooves formed in the housing **24**. The outer cylindrical surface **57** may be continuous along its length or it may be stepped having two or more different diameter portions. The input piston **34** includes a central bore **62** formed through the second end **52**. One or more lateral passageways **64** are formed through the input piston **34**. The lateral passageways **64** extend from the outer cylindrical surface **57** to the central bore **62** to provide fluid communication therebetween. The brake pedal unit **20** is in a "rest" position as shown in FIGS. **1** and **2**. In the "rest" position, the pedal **42** has not been depressed by the driver of the vehicle. In the rest position, the passageways **64** of the input piston **34** are between the seals **58** and **60**. In this position, the passageways **64** are in fluid communication with a conduit **66** formed though the housing **24**. The conduit **66** is in fluid communication with a conduit **68** formed in the housing **24**. The conduit **68** is in fluid communication with a reservoir port **70** connected to the reservoir **18**. A filter **69** may be disposed in the port **70** or the conduit **68**. The conduits **66** and **68** can be formed by various bores, grooves and passageways formed in the housing **24**. In the rest position, the passageways **64** are also in fluid communication with a conduit **72** formed in the housing **24** which leads to a simulation valve **74**. The simulation valve **74** may be a cut off valve which may be electrically operated. The simulation valve **74** may be mounted in the housing **24** or may be remotely located therefrom

The primary piston **38** is slidably disposed in the second bore **28** of the housing **24**. An outer wall **79** of the primary piston **38** is engaged with a lip seal **80** and a lip seal **81** mounted in grooves formed in the housing **24**. The primary piston **38** includes a first end **82** having a cavity **84** formed therein. A second end **86** of the primary piston **38** includes a cavity **88** formed therein. One or more passageways **85** are formed in the primary piston **38** which extend from the cavity **88** to the outer wall of the primary piston **38**. As shown in FIG. **2**, the passageway **85** is located between the lip seals **80** and **81** when the primary piston **38** is in its rest position. For reasons which will be explained below, the passageway **85** is in selective fluid communication with a conduit **154** which is in fluid communication with the reservoir **18**.

The central bore **62** of the input piston **34** and the cavity **84** of the primary piston **38** house various components defining a pedal simulator, indicated generally at **100**. A caged spring assembly, indicated generally at **102**, is defined by a pin **104**, a retainer **106**, and a low rate simulator spring **108**. The pin **104** is shown schematically as being part of the input piston **34** and disposed in the central bore **62**. The pin **104** could be configured as a pin having a first end which is press fit or threadably engaged with the input piston **34**. The pin **104** extends axially within the central bore **62** and into the cavity **84** of the primary piston **38**. A second end **112** of the pin **104** includes a circular flange **114** extending radially outwardly therefrom. The second end **112** is spaced from an elastomeric pad **118** disposed in the cavity **84**. The elastomeric pad **118** is axially aligned with the second end **112** of the pin **104**, the reason for which will be explained below. The retainer **106** of the caged spring assembly **102** includes a stepped through bore **122**. The stepped through bore **122** defines a shoulder **124**. The second end **112** of the pin **104** extends through the through bore **122**. The flange **114** of the pin **104** engages with the shoulder **124** of the retainer **106** to prevent the pin **104** and the retainer **106** from separating from each other. One end of the low rate simulator spring **108** engages with the second end **52** of the input piston **34**, and the other end of the low rate simulator spring **108** engages with the retainer **106** to bias the retainer **106** in a direction away from the pin **104**.

The pedal simulator **100** further includes a high rate simulator spring **130** which is disposed about the pin **104**. The terms low rate and high rate are used for description purposes and are not intended to be limiting. It should be understood that that the various springs of the pedal simulator **100** may have any suitable spring coefficient or spring rate. In the illustrated embodiment, the high rate simulator spring **130** preferably has a higher spring rate than the low rate simulator spring **108**. One end of the high rate simulator spring **130** engages with the bottom of the central bore **62** of the input piston **34**. The other end of the high rate simulator spring **130** is shown in FIG. **2** in a non-engaged position and spaced away from an end of the retainer **106**. The housing **24**, the input piston **34** (and its seals), and the primary piston **38** (and its seals) generally define a fluid simulation chamber **144**. The simulation chamber **144** is in fluid communication with a conduit **146** which is in fluid communication with the simulation valve **74**. A filter **145** may be housed within the conduit **146**.

As discussed above, the brake pedal unit **20** includes the primary and secondary pistons **38** and **40** that are disposed in the second and third bores **28** and **32**, respectively, which are formed in the housing **24**. The primary and secondary pistons **38** and **40** are generally coaxial with one another. A primary output conduit **156** is formed in the housing **24** and is in fluid communication with the second bore **28**. The primary output conduit **156** may be extended via external piping or a hose connected to the housing **24**. A secondary output conduit **166** is formed in the housing **24** and is in fluid communication with the third bore **30**. The secondary output conduit **166** may be extended via external piping or a hose connected to the housing **24**. As will be discussed in detail below, rightward movement of the primary and secondary pistons **38** and **40**, as viewing FIGS. **1** and **2**, provides pressurized fluid out through the conduits **156** and **166**, respectively. A return spring **151** is housed in the second bore **28** and biases the primary piston **38** in the leftward direction.

The secondary piston **40** is slidably disposed in the third bore **30**. An outer wall **152** of the secondary piston is engaged with a lip seal **153** and a lip seal **154** mounted in grooves formed in the housing **24**. A secondary pressure chamber **228** is generally defined by the third bore **30**, the secondary piston **40**, and the lip seal **154**. Rightward movement of the secondary piston **40**, as viewing FIGS. **1** and **2**, causes a buildup of pressure in the secondary pressure chamber **228**. The secondary pressure chamber **228** is in fluid communication with the secondary output conduit **166** such that pressurized fluid is selectively provided to the hydraulic control unit **14**. One or more passageways **155** are formed in the secondary piston **40**. The passageway **155** extends between the outer wall of the primary piston **38** and a right-hand end of the secondary piston **40**. As shown in FIG. **2**, the passageway **155** is located between the seal **153** and the lip seal **154** when the secondary piston **40** is in its rest position, the reason for which will be explained below. For reasons which will be explained below, the passageway **155** is in selective fluid communication with a conduit **164** which is in fluid communication with the reservoir **18**.

A primary pressure chamber **198** is generally defined by the second bore **28**, the primary piston **38**, the secondary piston **40**, the lip seal **81**, and the seal **153**. Although the various seals shown in the drawings are schematically represented as O-ring or lip seals, it should be understood that they can have any configuration. Rightward movement of the primary piston **38**, as viewing FIGS. **1** and **2**, causes a buildup of pressure in the primary pressure chamber **198**. The primary pressure chamber **198** is in fluid communication with the primary output conduit **156** such that pressurized fluid is selectively provided to the hydraulic control unit **14**.

The primary and secondary pistons **38** and **40** may be mechanically connected together such that there is limited play or movement between the pistons **38** and **40**. This type of connection permits the primary and secondary pistons **38** and **40** to move relative to one another by relatively small increments to compensate for pressure and/or volume differences in their respective output circuits. However, under certain failure modes it is desirable that the secondary piston **40** is connected to the primary piston **38**. For example, if the brake system **10** is under a manual push through mode, as will be explained in detail below, and additionally fluid pressure is lost in the output circuit relative to the secondary piston **40**, such as for example, in the conduit **166**, the secondary piston **40** will be forced or biased in the rightward direction due to the pressure within the primary chamber **1798**. If the primary and secondary pistons **38** and **40** were not connected together, the secondary piston **40** would freely travel to its further most right-hand position, as viewing FIGS. **1** and **2**, and the driver would have to depress the pedal **42** a distance to compensate for this loss in travel. However, because the primary and secondary pistons **38** and **40** are connected together, the secondary piston **40** is prevented from this movement and relatively little loss of travel occurs in this type of failure.

The primary and secondary pistons **38** and **40** can be connected together by any suitable manner. For example, as schematically shown in FIGS. **1** and **2**, a locking member **180** is disposed and trapped between the primary and secondary pistons **38** and **40**. The locking member **180** includes a first end **182** and a second end **184**. The first end **182** is trapped within the cavity **88** of the second end **86** of the primary piston **38**. The second end **184** of the locking member **180** is trapped within a recess or cavity **186** formed in the secondary piston **40**. The first and second ends **182** and **184** may include enlarged head portions which are trapped behind narrower openings **192** and **194** of the cavities **88** and **186**, respectively. A first spring **188** is housed within the cavity **88** of the primary piston **38** and biases the locking member **180** in a direction towards the primary piston **38** and away from the secondary piston **40**. A second spring **190** is housed within the cavity **186** of the secondary piston **40** and biases the locking member **180** in a direction towards the primary piston **38** and away from the secondary piston **40**. The springs **188** and **190** and the locking member **180** maintain the first and second output piston at a spaced apart distance from one another while permitting limited movement towards and away from each other by compression of the springs **188** or **190**. This limited play mechanical connection permits the primary and secondary pistons **38** and **40** to move relative to one another by small increments to compensate for pressure and/or volume differences in their respective output circuits.

Referring back to FIG. **1**, the system **10** may further include a travel sensor, schematically shown at **240** in FIG. **1**, for producing a signal that is indicative of the length of travel of the input piston **34** which is indicative of the pedal travel. The system **10** may also include a switch **252** for producing a signal for actuation of a brake light and to provide a signal indicative of movement of the input piston **34**. The brake system **10** may further include sensors such as pressure transducers **257** and **259** for monitoring the pressure in the conduits **156** and **166**, respectively.

The system **10** further includes a source of pressure in the form of a plunger assembly, indicated generally at **300**. As will be explained in detail below, the system **10** uses the plunger assembly **300** to provide a desired pressure level to the wheel brakes **16***a-d* during a normal boosted brake apply. Fluid from the wheel brakes **16***a-d* may be returned to the plunger assembly **300** or diverted to the reservoir **18**.

The system **10** further includes a first isolation valve **320** and a second isolation valve **322** (or referred to as switching valves or base brake valves). The isolation valves **320** and **322** may be solenoid actuated three way valves. The isolation valves **320** and **322** are generally operable to two positions, as schematically shown in FIG. **1**. The first isolation valve **320** has a port **320***a* in selective fluid communication with the primary output conduit **156** which is in fluid communication with the first output pressure chamber **198**. A port **320***b* is in selective fluid communication with a boost conduit **260**. A port **320***c* is in fluid communication with a conduit **324** which is selectively in fluid communication with the wheel brakes **16***a* and **16***d*. The second isolation valve **322** has a port **322***a* in selective fluid communication with the conduit **166** which is in fluid communication with the second output pressure chamber **228**. A port **322***b* is in selective fluid communication with the boost conduit **260**. A port **322***c* is in fluid communication with a conduit **326** which is selectively in fluid communication with the wheel brakes **16***b* and **16***c*.

The system **10** further includes various valves (slip control valve arrangement) for permitting controlled braking operations, such as ABS, traction control, vehicle stability control, and regenerative braking blending. A first set of valves includes an apply valve **340** and a dump valve **342** in fluid communication with the conduit **324** for cooperatively supplying brake fluid received from the boost valves to the wheel brake **16***d*, and for cooperatively relieving pressurized brake fluid from the wheel brake **16***d* to a reservoir conduit **343** in fluid communication with the reservoir conduit **296**. A second set of valves include an apply valve **344** and a dump valve **346** in fluid communication with the conduit **324** for cooperatively supplying brake fluid received from the boost valves to the wheel brake **16***a*, and for cooperatively relieving pressurized brake fluid from the wheel brake **16***a* to the reservoir conduit **343**. A third set of valves include an apply valve **348** and a dump valve **350** in fluid communication with the conduit **326** for cooperatively supplying brake fluid received from the boost valves to the wheel brake **16***c*, and for cooperatively relieving pressurized brake fluid from the wheel brake **16***c* to the reservoir conduit **343**. A fourth set of valves include an apply valve **352** and a dump valve **354** in fluid communication with the conduit **326** for cooperatively supplying brake fluid received from the boost valves to the wheel brake **16***d*, and for cooperatively relieving pressurized brake fluid from the wheel brake **16***d* to the reservoir conduit **343**.

As stated above, the system **10** includes a source of pressure in the form of the plunger assembly **300** to provide a desired pressure level to the wheel brakes **16***a-d*. The system **10** further includes a venting valve **302** and a pumping valve **304** which cooperate with the plunger assembly **300** to provide boost pressure to the boost conduit **260** for actuation of the wheel brakes **16***a-d*. The venting valve **302** and the pumping valve **304** may be solenoid actuated valves movable between open positions and closed positions. In the closed positions, the venting valve **302** and the pumping valve **304** may still permit flow in one direction as schematically shown as a check valve in FIG. **1**. The venting valve **302** is in fluid communication with the reservoir conduit **296** and a first output conduit **306** in fluid communication with the plunger assembly **300**. A second output conduit **308** is in fluid communication between the plunger assembly **300** and the boost conduit **260**.

As best shown in FIG. **3**, the plunger assembly **300** includes a housing **400** having a multi-stepped bore **402** formed therein. The bore **402** includes a first portion **404**, a second portion **406**, and third portion **408**. A piston **410** is slidably disposed with the bore **402**. The piston **410** includes an enlarged end portion **412** connected to a smaller diameter central portion **414**. The piston **410** has a second end **416** connected to a ball screw mechanism, indicated generally at **420**. The ball screw mechanism **420** is provided to impart translational or linear motion of the piston **410** along an axis defined by the bore **402** in both a forward direction (rightward as viewing FIGS. **1** and **3**), and a rearward direction (leftward as viewing FIGS. **1** and **3**) within the bore **402** of the housing **400**. In the embodiment shown, the ball screw mechanism **420** includes a motor **422** rotatably driving a screw shaft **424**. The motor **422** may include a sensor **426** for detecting the rotational position of the motor **422** and/or ball screw mechanism **420** which is indicative of the position of the piston **410**. The second end **416** of the piston **410** includes a threaded bore **430** and functions as a driven nut of the ball screw mechanism **420**. The ball screw mechanism **420** includes a plurality of balls **432** that are retained within helical raceways formed in the screw shaft **424** and the threaded bore **430** of the piston **410** to reduce friction. Although a ball screw mechanism **420** is shown and described with respect to the plunger assembly **300**, it should be understood that other suitable mechanical linear actuators may be used for imparting movement of the piston **410**. It should also be understood that although the piston **410** functions as the nut of the ball screw mechanism **420**, the piston **410** could be configured to function as a screw shaft of the ball screw mechanism **420**. Of course, under this circumstance, the screw shaft **424** would be configured to function as a nut having internal helical raceways formed therein.

As will be discussed in detail below, the plunger assembly **300** can provide boosted pressure to the boost conduit **260** when actuated in both the forward and rearward directions. The plunger assembly **300** includes a seal **440** mounted on the enlarged end portion **412** of the piston **410**. The seal **440** slidably engages with the inner cylindrical surface of the first portion **404** of the bore **2** as the piston **410** moves within the bore **402**. A pair of seals **442** and **444** is mounted in grooves formed in the second portion **406** of the bore **402**. The seals **442** and **444** slidably engage with the outer cylindrical surface of the central portion **414** of the piston **410**. A first pressure chamber **450** is generally defined by the first portion **404** of the bore **402**, the enlarged end portion **412** of the piston **410**, and the seal **440**. A second pressure chamber **452**, located generally behind the enlarged end portion **412** of the piston **410**, is generally defined by the first and second portions **404** and **406** of the bore **402**, the seals **442** and **444**, and the central portion **414** of the piston **410**. The seals **440**, **442**, and **44** can have any suitable seal structure. In one embodiment, the seal **440** is a quad ring seal. Although a lip seal may also be suitable for the seal **440**, a lip seal is more generally more compliant and requires more volume displacement for a given pressure differential. This may result in a small boost pressure reduction when the piston **410** travels in the rearward direction during a pumping mode.

As stated above, the brake pedal unit assembly **12** includes a simulation valve **74** which may be mounted in the housing **24** or remotely from the housing **24**. As schematically shown in FIGS. **1** and **2**, the simulation valve **74** may be a solenoid actuated valve. The simulation valve **74** includes a first port **75** and a second port **77**. The port **75** is in fluid communication with the conduit **146** which is in fluid communication with the simulation chamber **144**. The port **77** is in fluid communication with the conduit **72** which is in fluid communication with the reservoir **18** via the conduits **66** and **68**. The simulation valve **74** is movable between a first position **74*a*** restricting the flow of fluid from the simulation chamber **144** to the reservoir **18**, and a second position **74*b*** permitting the flow of fluid between the reservoir **18** and the simulation chamber **144**. The simulation valve **74** is in the first position or normally closed position when not actuated such that fluid is prevented from flowing out of the simulation chamber **144** through conduit **72**, as will be explained in detail below.

The following is a description of the operation of the brake system **10**. FIGS. **1** and **2** illustrate the brake system **10** and the brake pedal unit **20** in the rest position. In this condition, the driver is not depressing the brake pedal **42**. Also in the rest condition, the simulation valve **74** may be energized or not energized. During a typical braking condition, the brake pedal **42** is depressed by the driver of the vehicle. The brake pedal **42** is coupled to the travel sensor **240** for producing a signal that is indicative of the length of travel of the input piston **34** and providing the signal to an electronic control module (not shown). The control module may include a microprocessor. The control module receives various signals, processes signals, and controls the operation of various electrical components of the brake system **10** in response to the received signals. The control module can be connected to various sensors such as pressure sensors, travel sensors, switches, wheel speed sensors, and steering angle sensors. The control module may also be connected to an external module (not shown) for receiving information related to yaw rate, lateral acceleration, longitudinal acceleration of the vehicle such as for controlling the brake system **10** during vehicle stability operation. Additionally, the control module may be connected to the instrument cluster for collecting and supplying information related to warning indicators such as ABS warning light, brake fluid level warning light, and traction control/vehicle stability control indicator light.

During normal braking operations (normal boost apply braking operation) the plunger assembly **300** is operated to provide boost pressure to the boost conduit **260** for actuation of the wheel brakes **16*a-d***. Under certain driving conditions, the control module communicates with a powertrain control module (not shown) and other additional braking controllers of the vehicle to provide coordinated braking during advanced braking control schemes (e.g., anti-lock braking (AB), traction control (TC), vehicle stability control (VSC), and regenerative brake blending). During a normal boost apply braking operation, the flow of pressurized fluid from the brake pedal unit **20** generated by depression of the brake pedal **42** is diverted into the internal pedal simulator assembly **100**. The simulation valve **74** is actuated to divert fluid through the simulation valve **74** from the simulation chamber **144** to the reservoir **18** via the conduits **146**, **72**, **66**, and **68**. Note that fluid flow from the simulation chamber **144** to the reservoir **18** is closed off once the passageways **64** in the input piston **34** move past the seal **60**. Prior to movement of the input piston **34**, as shown in FIGS. **1** and **2**, the simulation chamber **144** is in fluid communication with the reservoir **18** via the conduits **66** and **68**.

During the duration of the normal braking mode, the simulation valve **74** remains open permitting the fluid to flow from the simulation chamber **144** to the reservoir **18**. The fluid within the simulation chamber **144** is non-pressurized and is under very low pressures, such as atmospheric or low reservoir pressure. This non-pressurized configuration has an advantage of not subjecting the sealing surfaces of the pedal simulator to large frictional forces from seals acting against surfaces due to high pressure fluid. In conventional pedal simulators, the piston(s) are under increasingly high pressures as the brake pedal is depressed subjecting them large frictional forces from the seals, thereby adversely effecting the pedal feel.

Also during the normal boost apply braking operation, the isolation valves **320** and **322** are energized to a secondary position to prevent the flow of fluid from the conduits **156** and **166** through the valves **320** and **322**. Fluid flow is prevented from flowing from the ports **320***a* and **322***a* to the ports **320***c* and **322***c*, respectively. Thus, the fluid within the first and second output pressure chambers **198** and **228** of the brake pressure unit **20** are fluidly locked which generally prevents the first and second output pistons **38** and **40** from moving further. More specifically, during the initial stage of the normal boost apply braking operation, movement of the input rod **45** causes movement of the input piston **34** in a rightward direction, as viewing FIG. **2**. Initial movement of the input piston **34** causes movement of the primary piston **38** via the low rate simulator spring **108**. Movement of the primary piston **38** causes initial movement of the secondary piston **40** due to the mechanical connection therebetween by the locking member **180** and the springs **188** and **190**. Note that during this initial movement of the primary piston **38**, fluid is free to flow from the primary pressure chamber **198** to the reservoir **18** via conduits **85**, **154**, and **68** until the conduit **85** moves past the seal **81**. Also, during initial movement of the secondary piston **40**, fluid is free to flow from the secondary pressure chamber **228** to the reservoir **18** via the conduits **155** and **164** until the conduit **155** moves past the seal **154**.

After the primary and secondary pistons **38** and **40** stop moving (by closing of the conduits **85** and **155** and closing of the first and second base brake valves **320** and **322**), the input piston **34** continues to move rightward, as viewing FIGS. **1** and **2**, upon further movement by the driver depressing the brake pedal **42**. Further movement of the input piston **34** compresses the various springs of the pedal simulator assembly **100**, thereby providing a feedback force to the driver of the vehicle.

During normal braking operations (normal boost apply braking operation) while the pedal simulator assembly **100** is being actuated by depression of the brake pedal **42**, the plunger assembly **300** can be actuated by the electronic control unit to provide actuation of the wheel brakes **16***a-d*. Actuation of the isolation valves **320** and **322** to their secondary positions to prevent the flow of fluid from the conduits **156** and **166** through the valves **320** and **322** isolates the brake pedal unit **20** from the wheel brakes **16***a-d*. The plunger assembly **300** may provide "boosted" or higher pressure levels to the wheel brakes **16***a-d* compared to the pressure generated by the brake pedal unit **20** by the driver depressing the brake pedal **42**. Thus, the system **10** provides for assisted braking in which boosted pressure is supplied to the wheel brakes **16***a-d* during a normal boost apply braking operation helping reduce the force required by the driver acting on the brake pedal **42**.

To actuate the wheel brakes **16***a-d* via the plunger assembly **300** when in its rest position, as shown in FIGS. **1** and **3**, the electronic control unit energizes the venting valve **302** to its closed position, as shown in FIG. **1**, such that fluid is prevented from venting to reservoir by flowing from the conduit **306** to the conduit **296**. The pumping valve **304** is de-energized to its open position, as shown in FIG. **1**, to permit flow of fluid through the pumping valve **304**. The electronic control unit actuates the motor **422** in a first rotational direction to rotate the screw shaft **424** in the first rotational direction. Rotation of the screw shaft **424** in the first rotational direction causes the piston **410** to advance in the forward direction (rightward as viewing FIGS. **1** and **3**). Movement of the piston **410** causes a pressure increase in the first pressure chamber **450** and fluid to flow out of the first pressure chamber **450** and into the conduit **306**. Fluid can flow into the boost conduit **260** via the open pumping valve **304**. Note that fluid is permitted to flow into the second pressure chamber **452** via the conduit **308** as the piston **410** advances in the forward direction. Pressurized fluid from the boost conduit **260** is directed into the conduits **324** and **326** through the isolation valves **320** and **322**. The pressurized fluid from the conduits **324** and **326** can be directed to the wheel brakes **16***a-d* through opened apply valves **340**, **344**, **348**, and **352** while the dump valves **342**, **346**, **350**, and **354** remain closed. When the driver releases the brake pedal **42**, the pressurized fluid from the wheel brakes **16***a-d* may back drive the ball screw mechanism **420** moving the piston **410** back to its rest position. Under certain circumstances, it may also be desirable to actuate the motor **422** of the plunger assembly **300** to retract the piston **410** withdrawing the fluid from the wheel brakes **16***a-d*. During a forward stroke of the plunger assembly **300**, the pumping valve **304** may be in its open position or held closed

During a braking event, the electronic control module can also selectively actuate the apply valves **340**, **344**, **348**, and **352** and the dump valves **342**, **346**, **350**, and **354** to provide a desired pressure level to the wheel brakes **16***d*, **16***a*, **16***c*, and **16***b*, respectively.

In some situations, the piston **410** of the plunger assembly **300** may reach its full stroke length within the bore **402** of the housing **400** and additional boosted pressure is still desired to be delivered to the wheel brakes **16**-*d*. The plunger assembly **300** is a dual acting plunger assembly such that it is configured to also provide boosted pressure to the boost conduit **260** when the piston **410** is stroked rearwardly. This has the advantage over a conventional plunger assembly that first requires its piston to be brought back to its rest or retracted position before it can again advance the piston to create pressure within a single pressure chamber. If the piston **410** has reached its full stroke, for example, and additional boosted pressure is still desired, the pumping valve **304** is energized to its closed check valve position. The venting valve **302** may be de-energized to its open position. Alternatively, the venting valve **302** may be left energized in its closed to permit fluid flow through its check valve during a pumping mode. The electronic control unit actuates the motor **422** in a second rotational direction opposite the first rotational direction to rotate the screw shaft **424** in the second rotational direction. Rotation of the screw shaft **424** in the second rotational direction causes the piston **410** to retract or move in the rearward direction (leftward as viewing FIGS. **1** and **3**). Movement of the piston **410** causes a pressure increase in the second pressure chamber **452** and fluid to flow out of the second pressure chamber **452** and into the conduit **308**. Note that fluid is permitted to flow into the first pressure chamber **450** via the conduits **306** and **296** as the piston **410** moves rearwardly or in its return stroke. Pressurized fluid from the boost conduit **260** is directed into the conduits **324** and **326** through the isolation valves **320** and **322**. The pressurized fluid from the conduits **324** and **326** can be directed to the wheel brakes **16***a-d* through the opened apply valves **340**, **344**, **348**, and **352** while dump valves **342**, **346**, **350**, and **354** remain closed. In a similar manner as during a forward stroke of the piston **410**, the electronic control module can also selectively actuate the apply valves **340**, **344**, **348**, and **352** and the dump valves **342**, **346**, **350**, and **354** to provide a desired pressure level to the wheel brakes **16***d*, **16***a*, **16***c*, and **16***b*, respectively.

As shown in FIG. **3**, the first portion **404** of the bore **402** generally has a fluid diameter D_1 corresponding to where the outer diameter of the seal **440** slides along the inner cylindrical surface of the first portion **404** of the bore **402**. The second portion **406** of the bore **402** generally has a fluid diameter D_2 corresponding to inner diameter of the seal **442** sliding against the outer diameter of the central portion **414** of the piston **410**. The first pressure chamber **450** generally has an effective hydraulic area corresponding to the diameter D_2 since fluid is diverted through the conduits **306**, **260**, and **308** as the piston **410** is advanced in the forward direction. The second pressure chamber **452** has an effective hydraulic area corresponding to the diameter D_1 minus the diameter D_2. The plunger assembly **300** can be configured to have any suitable dimensions for the diameters D_1 and D_2. In one embodiment, the diameters D_1 and D_2 can be configured such that the effective area defined by D_1 can be greater than the annular effective area defined by D_1 and D_2. This configuration provides that on the back stroke in which the piston is moving rearwardly, less torque (or power) is required by the motor **422** to maintain the same pressure as in its forward stroke. Besides using less power, the motor **422** may also generate less heat during the rearward stroke of piston **410**. Under circumstances in which the driver presses on the pedal **42** for long durations, the plunger assembly **300** could be operated to apply a rearward stroke of the piston **410** to prevent overheating of the motor **422**. Note that the chamber **450** should be sized larger than the chamber **452**.

Instead of using the apply valves **340**, **344**, **348**, and **352** and the dump valves **342**, **346**, **350**, and **354** to provide a desired pressure level to the wheel brakes **16*d***, **16*a***, **16*c***, and **16*b***, the system **10** could replace the apply and dump valves with single control valves (not shown) in the conduits corresponding to the wheel brakes **16*a-d***. The control valves can be actuated individually, in a multiplexing manner, between their open and closed positions to provide different braking pressures within the wheel brakes **16*a-d***. This may be used during various braking functions such as anti-lock braking, traction control, dynamic rear proportioning, vehicle stability control, hill hold, and regenerative braking Pressurized fluid is returned from the wheel brakes **16*a-d*** to the plunger assembly **300** through the control valves instead of being diverted to the reservoir. In this situation, the plunger assembly **300** is preferably configured and operated by the electronic control unit (not shown) such that relatively small rotational increments of the motor **422** and/or ball screw mechanism **420** are obtainable. Thus, small volumes of fluid and relatively minute pressure levels are able to be applied and removed from the conduits associated with the wheel brakes **16*a-d***. For example, the motor **422** may be actuated to turn 0.5 of a degree to provide a relatively small amount of fluid and pressure increase. This enables a multiplexing arrangement such that the plunger assembly **300** can be controlled to provide individual wheel pressure control. Thus, the plunger assembly **300** and the system **10** can be operated to provide individual control for the wheel brakes **16*a-d*** or can be used to control one or more wheel brakes **16*a-d*** simultaneously by opening and closing the appropriate control valves (not shown).

In the event of a loss of electrical power to portions of the brake system **10**, the brake system **10** provides for manual push through or manual apply such that the brake pedal unit **20** can supply relatively high pressure fluid to the primary output conduit **156** and the secondary output conduit **166**. During an electrical failure, the motor **422** of the plunger assembly **300** might cease to operate, thereby failing to produce pressurized hydraulic brake fluid from the plunger assembly **300**. The isolation valves **320** and **324** will shuttle (or remain) in their positions to permit fluid flow from the conduits **156** and **166** to the wheel brakes **16*a-d***. The simulation valve **74** is shuttled to its closed position **74*a***, as shown in FIGS. **1** and **2**, to prevent fluid from flowing out of the simulation chamber **144** to the reservoir **18**. Thus, moving the simulation valve **74** to its closed position **74*a*** hydraulically locks the simulation chamber **144** trapping fluid therein. During the manual push-through apply, the primary and secondary output pistons **38** and **40** will advance rightward pressurizing the chambers **198** and **228**, respectively. Fluid flows from the chambers **198** and **228** into the conduits **156** and **166**, respectively, to actuate the wheel brakes **16*a-d*** as described above.

During the manual push-through apply, initial movement of the input piston **34** forces the spring(s) of the pedal simulator to start moving the pistons **38** and **40**. After further movement of the input piston **34**, in which the fluid within the simulation chamber **144** is trapped or hydraulically locked, further movement of the input piston **34** pressurizes the simulation chamber **144** causing movement of the primary piston **38** which also causes movement of the secondary piston **40** due to pressurizing of the primary chamber **144**. As shown in FIGS. **1** and **2**, the input piston **34** has a smaller diameter (about the seal **60**) than the diameter of the primary piston **38** (about the seal **80**). Since the hydraulic effective area of the input piston **34** is less than the hydraulic effective area of the primary piston **38**, the input piston **34** may travel more axially in the right-hand direction as viewing FIGS. **1** and **2** than the primary piston **38**. An advantage of this configuration is that although a reduced diameter effective area of the input piston **34** compared to the larger diameter effective area of the primary piston **38** requires further travel, the force input by the driver's foot is reduced. Thus, less force is required by the driver acting on the brake pedal **42** to pressurize the wheel brakes compared to a system in which the input piston and the primary piston have equal diameters.

In another example of a failed condition of the brake system **10**, the hydraulic control unit **12** may fail as discussed above and furthermore one of the output pressure chambers **198** and **228** may be reduced to zero or reservoir pressure, such as failure of a seal or a leak in one of the conduits **156** or **166**. The mechanical connection of the primary and secondary pistons **38** and **40** prevents a large gap or distance between the pistons **38** and **40** and prevents having to advance the pistons **38** and **40** over a relatively large distance without any increase in pressure in the non-failed circuit. For example, if the brake system **10** is under a manual push through mode and additionally fluid pressure is lost in the output circuit relative to the secondary piston **40**, such as for example in the conduit **166**, the secondary piston **40** will be forced or biased in the rightward direction due to the pressure within the primary chamber **198**. If the primary and secondary pistons **38** and **40** were not connected together, the secondary piston **40** would freely travel to its further most right-hand position, as viewing FIGS. **1** and **2**, and the driver would have to depress the pedal **42** a distance to compensate for this loss in travel. However, because the primary and secondary pistons **38** and **40** are connected together through the locking member **180**, the secondary piston **40** is prevented from this movement and relatively little loss of travel occurs in this type of failure. Thus, the maximum volume of the primary pressure chamber **198** is limited had the secondary piston **40** not be connected to the primary piston **38**.

In another example, if the brake system **10** is under a manual push through mode and additionally fluid pressure is lost in the output circuit relative to the primary piston **40**, such as for example, in the conduit **156**, the secondary piston **40** will be forced or biased in the leftward direction due to the pressure within the secondary chamber **228**. Due to the configuration of the brake pedal unit **20**, the left-hand end of the secondary piston **40** is relatively close to the right-hand end of the primary piston **38**. Thus, movement of the secondary piston **40** towards the primary piston **38** during this loss of pressure is reduced compared to a conventional master cylinder in which the primary and secondary pistons have equal diameters and are slidably disposed in the same diameter bore. To accomplish this advantage, the housing **24** of the brake pedal unit **20** includes a stepped bore arrangement such that diameter of the second bore **28** which houses the primary piston **38** is larger than the third bore **30** housing the secondary piston **40**. A portion of the primary chamber **198** includes an annular region surrounding a left-hand portion of the secondary piston **40** such that the primary and secondary pistons **38** and **40** can remain relatively close to one another during a manual push-through operation. In the configuration shown, the primary and secondary pistons **38** and **40** travel together during a manual push-through operation in which both of the circuits corresponding to the conduits **156** and **166** are intact. This same travel speed is due to the hydraulic effective areas of the pistons **38** and **40**, for their respective output pressure chambers **198** and **228**, are approximately equal. In a preferred embodiment, the area of the diameter of the secondary piston **40** is approximately equal to the area of the diameter of the primary piston **38** minus the area of the diameter of the secondary piston **40**. Of course, the brake pedal unit **20** could be configured differently such that the primary and secondary pistons **38** and **40** travel at different speeds and distances during a manual push though operation.

During a manual push-through operation in which both of the circuits corresponding to the conduits **156** and **166** are intact, such as during an electrical failure described above, the combined hydraulic effective area of the primary and secondary pistons **38** and **40** is the area of the diameter of the primary piston **38**. However, during a failure of one of the circuits corresponding to the conduits **156** and **166**, such as by a leak in the conduit **166**, the hydraulic effective area is halved such that the driver can now generate double the pressure within the primary chamber **198** and the non-failed conduit **156** when advancing the primary piston **38** during a manual push-through operation via depression of the brake pedal **42**. Thus, even though the driver is actuating only two of the wheel brakes **16*a*** and **16*d*** during this manual push through operation, a greater pressure is obtainable in the non-failed primary chamber **198**. Of course, the stroke length of the primary piston **38** will need to be increased to compensate.

There is illustrated in FIG. **4** an alternate embodiment of a plunger assembly, indicated generally at **500**, which may be used for the plunger assembly **300** in the brake system **10**, for example. The plunger assembly **500** includes a housing **502** having a multi-stepped bore **504** formed therein. If installed into the system **10**, the conduits **296**, **306**, and **308** are in fluid communication with the bore **504**. A hollow sleeve **510** may be inserted into the bore **504**. Although the components of the plunger assembly **500** may be made of any suitable material, the housing **502** may be made of aluminum for weight reduction while the sleeve **510** may be made of a hard coat anodized metal for accepting a piston assembly **511** slidably disposed therein. The sleeve **510** has a multi-stepped inner bore including a first portion **512**, a second portion **514**, and a third portion **516** (similar to the first portion **404**, the second portion **406**, and the third portion **408** of the bore **402** of the plunger assembly **300**).

The plunger assembly **500** further includes a ball screw mechanism, indicated generally at **520**. The ball screw mechanism **520** includes a motor **522** having an outer housing **523** which houses a stator **524** for rotating a rotor **526**. The rotor **526** rotates a screw shaft **528** extending along the axis of the plunger assembly **500**. A rear end of the rotor **526** is supported in the housing **523** by a bearing assembly **527**. The front end of the rotor **526** is connected to a multi-piece support assembly **531** which is supported by a pair of bearing assemblies **533** and **535** mounted in the bore **504** of the housing **502**. The bearing assemblies **527**, **533**, and **535** are shown as ball bearing assemblies having upper and lower races. However, it should be understood that the bearings assemblies **531**, **533**, and **535** can be any suitable structure.

The piston assembly **511** includes a piston **530** threadably attached to an intermediate connector **532** which is threadably attached to a nut **534**. The nut **534** includes an internal threaded bore **536** having helical raceways formed therein for retaining a plurality of balls **538**. The balls **538** are also retained in raceways **540** formed in the outer surface of the screw shaft **528**, thereby functioning as a ball screw drive mechanism. To prevent rotation of the piston assembly **511**, the plunger **500** can include an anti-rotation device including a pin **542** extending radially outwardly from the intermediate connector **532**. A bearing assembly **544** is attached to the pin **542** and rolls along a slot **546** formed in the third portion **516** of the sleeve **510**. Of course, any suitable anti-rotation device may be used. Also, although a single anti-rotation device is shown and described, the plunger assembly **500** can have one or more, such as for example, a pair of anti-rotation devices arranged 180 degrees apart from one another.

The piston **530** of the piston assembly **511** includes an outer cylindrical surface **550** which sealing engages with a pair of lip seals **552** and **554** mounted in grooves formed in the sleeve **510**. Radial passageways **556** are formed through the sleeve **510** which are in fluid communication with the reservoir conduit **296**. The piston **530** includes an enlarged end portion **560** and a smaller diameter central portion **562**. A seal, such as quad seal **564** is mounted in a groove formed in the enlarged end portion **560** of the piston **530**. The seals **552**, **554**, and **564** function similarly to the seals **442**, **444**, and **440** of the plunger assembly **300** described above.

The piston **530** of the piston assembly **511** may optionally include a stop cushion assembly, indicated generally at **570**. The stop cushion assembly **570** includes end member **572** connected to the end of the piston **530** by a bolt **574** or other fastener. The end member **572** is disposed in a recess **576** formed in the piston **530** and is mounted by the bolt **574** such that the end member **572** may move a limited amount relative to the piston **530**. A spring member, such as a plurality of disc springs **578** (or Belleville washer or spring washers) bias the end member **572** in a direction away from the piston **530**. The right-hand most end of the end member **572**, as viewing FIG. **4**, extends past the end of the piston **530**. The stop cushion assembly **570** provides for a cushioned stop if the end of the piston **530** engages with a bottom wall **579** of the bore **504** by compression of the springs **578**.

The piston assembly **511** may also include an optional rear stop cushion assembly, indicated generally at **580**. The rear stop cushion assembly **580** includes a disc spring **582** disposed about the screw shaft **528** and engages with the end wall of the nut **534** of the piston assembly **511**. The disc spring **582** may slightly compress when the piston assembly **511** is moved back its fully rested position.

A first pressure chamber **590** is generally defined by the sleeve **510**, the bore **504**, the enlarged end portion **560** of the piston **530**, and the seal **564**. A second pressure chamber **592**, located generally behind the enlarged end portion **560** of the piston **530**, is generally defined by the sleeve **510**, the bore **504**, the seals **552** and **564**, and the piston **530**. Passageways

594 are formed through the sleeve 510 and are in fluid communication with the second pressure chamber 592 and the conduit 308.

The piston assembly 500 operates in a similar manner as the plunger assembly 300 and will be described as being used in the system 10. For example, to actuate the wheel brakes 16*a-d* when the plunger assembly 500 is in its rest position, as shown in FIG. 4, the electronic control unit actuates the motor 522 in a first rotational direction to rotate the screw shaft 528 in the first rotational direction. Rotation of the screw shaft 528 in the first rotational direction causes the piston assembly 511 to advance in the forward direction (rightward as viewing FIGS. 1 and 3). Movement of the piston assembly 511 causes a pressure increase in the first pressure chamber 590 and fluid to flow out of the first pressure chamber 590 and into the conduit 306. Fluid can flow into the boost conduit 260 via the open pumping valve 304 or the check valve if the pumping valve 304 was in its closed position. Note that fluid is permitted to flow into the second pressure chamber 592 via the conduit 308 as the piston assembly 511 advances in the forward direction. Pressurized fluid from the boost conduit 260 is directed into the conduits 324 and 326 through the isolation valves 320 and 322. The pressurized fluid from the conduits 324 and 326 can be directed to the wheel brakes 16*a-d* through opened apply valves 340, 344, 348, and 352 while the dump valves 342, 346, 350, and 354 remain closed. When the driver releases the brake pedal 42, the pressurized fluid from the wheel brakes 16*a-d* may back drive the ball screw mechanism 420 moving the piston 410 back towards its rest position.

The plunger assembly 500 is a dual acting plunger assembly such that it is configured to also provide boosted pressure to the boost conduit 260 when the piston assembly 511 is stroked rearwardly. The electronic control unit actuates the motor 522 in a second rotational direction opposite the first rotational direction to rotate the screw shaft 528 in the second rotational direction. Rotation of the screw shaft 528 in the second rotational direction causes the piston assembly 511 to retract or move in the rearward direction (leftward as viewing FIGS. 1 and 3). Movement of the piston 530 causes a pressure increase in the second pressure chamber 592 and fluid to flow out of the second pressure chamber 592 and into the conduit 308. Pressurized fluid from the boost conduit 260 is directed into the conduits 324 and 326 through the isolation valves 320 and 322. The pressurized fluid from the conduits 324 and 326 can be directed to the wheel brakes 16*a-d* through the opened apply valves 340, 344, 348, and 352 while dump valves 342, 346, 350, and 354 remain closed. The pumping valve may be closed such that low pressure fluid fills the first pressure chamber 590.

There is illustrated in FIG. 5 a schematic illustration of a second embodiment of a brake system, indicated generally at 600. The brake system 600 is similar to the brake system 10 of FIG. 1 and, therefore, like functions and structures will not be described. Similar to the brake system 10, the brake system 600 includes a brake pedal unit 612, a hydraulic control unit 614, and wheel brakes 616*a-d*.

The brake system 600 does not include a venting valve like the venting valve 302 of the system 10. Instead, the brake system 600 includes a plunger assembly 620 similar to the plunger assembly 300. One of the differences is that the plunger assembly 620 has a piston 622 with a check valve 624 mounted therein. The check valve 624 permits fluid to flow from a first pressure chamber 630 to a reservoir conduit 632 (in communication with a reservoir 613) via a conduit 634 within the piston 622. It is noted that the check valve 624 prevents the flow of fluid from the reservoir 613 to the first pressure chamber 630 via the conduit 634. The check valve 624 also prevents the flow of fluid though the piston 622 from a second pressure chamber 636 to the first pressure chamber 630.

The system 600 includes a pumping valve 640 and a check valve 642. The check valve 642 is located within a conduit 644. The check valve 642 restricts the flow of fluid from the first pressure chamber 630 to the reservoir 613, while permitting the flow of fluid from the reservoir 613 to the pumping valve 640 and first pressure chamber 630. The pumping valve 640 is movable between an open position to permit the flow of fluid out of the first pressure chamber 630 and to a boost conduit 650 for delivering pressurized fluid to the wheel brakes 616*a-d*.

When the piston 622 advances in the forward direction, rightward as viewing FIG. 5, fluid flows out of the first pressure chamber 630 and through the de-energized pumping valve 640 into the boost conduit 650. Note that fluid is permitted to flow into the second pressure chamber 636. In the reverse stroke of the piston 622, the pumping valve 650 is energized to a closed position and fluid flows out of the second pressure chamber 636 but is prevented from flowing past the check valve 624 into the first pressure chamber 630. Note that in a reverse stroke, the piston 622 will have been moved rightward as viewing FIG. 5 such that the conduit 634 is to the right of a lip seal 637 to prevent fluid flow into the reservoir 613 from the second pressure chamber 636 via the conduit 634.

One of the advantages of the brake system 600 is a reduced cost due to not having to have a solenoid actuated venting valve. Additionally, there may not be a need to maintain power to the motor of the plunger assembly 620 on every brake apply. Another advantage is that the pumping valve only requires a small, low force, low cost, low current draw solenoid since it may hydraulically latch in a closed position as indicated by the dotted line 617 in FIG. 5. Under certain situations, the system 10 may need to be controlled to de-latch the valve 640.

There is illustrated in FIG. 6 an alternate embodiment of a plunger assembly, indicated generally at 700, which may be used for the plunger assembly 620 in the brake system 600, for example. The plunger assembly 700 includes a housing 702 having a multi-stepped bore 704 formed therein. If installed into the system 600, the conduits 632, 644, and 650 are in fluid communication with the bore 704. A hollow sleeve 710 may be inserted into the bore 504. Although the components of the plunger assembly 700 may be made of any suitable material, the housing 702 may be made of aluminum for weight reduction while the sleeve 710 may be made of a hard coat anodized metal for accepting a piston assembly 711 slidably disposed therein. The sleeve 710 has a multi-stepped inner bore including a first portion 712 and a second portion 714. Instead of a third portion, a tube 716 is press fit or slip fit onto the end of the second portion 714. The tube 716 may be made of an inexpensive material, such as extruded aluminum, instead of utilizing an expensive portion of the sleeve 710.

The plunger assembly 700 further includes a ball screw mechanism, indicated generally at 720. The ball screw mechanism 720 includes a motor 722 having an outer housing 723 which houses a stator 724 for rotating a rotor 726. The rotor 726 rotates a screw shaft 728 extending along the axis of the plunger assembly 700. The front end of the rotor 526 is connected to a multi-piece support assembly 731 which is supported by generally inexpensive needle bearings (compared to more expensive roller angular contact ball bearings as shown in FIG. 4). In particular, the plunger assembly 700 includes a pair of thrust needle bearings **735** and **737** and a radial needle bearing **739**. The bearings engage with features of the support assembly **731**.

The piston assembly **711** includes a piston **730** threadably attached to a nut **734**. The nut **734** includes an internal threaded bore **736** having helical raceways formed therein for retaining a plurality of balls **738**. The balls **738** are also retained in raceways **740** formed in the outer surface of the screw shaft **728**, thereby functioning as a ball screw drive mechanism. To prevent rotation of the piston assembly **711**, the plunger **700** can include an anti-rotation device including one or more bushings **745** that slide within corresponding slots **746** formed in the tube **716**. Of course, any suitable anti-rotation device may be used.

The piston **730** of the piston assembly **711** includes an outer cylindrical surface **750** which sealing engages with a pair of seals **752** and **754** mounted in grooves formed in the sleeve **710**. Radial passageways **756** are formed through the sleeve **710** which are in fluid communication with the reservoir conduit **632**. The piston **730** includes an enlarged end portion **760** and a smaller diameter central portion **762**. A seal, such as quad seal **764** is mounted in a groove formed in the enlarged end portion **760** of the piston **730**.

The plunger assembly **700** may include a check valve assembly **770** located in the enlarged end portion **760** of the piston **730**. The check valve **770** is similar in function to the check valve **624** of the system **600**. The check valve assembly **770** includes a ball **771** selectively seated on a valve seat **772** fixed relative to the piston **730**. A generally small or weak spring **773** biases the ball **771** onto the valve seat **772**.

The piston assembly **711** may also include an optional rear stop cushion assembly, indicated generally at **780**. The rear stop cushion assembly **780** includes one or more disc spring **782** disposed about the screw shaft **728** and engaged with the end wall of the nut **734** of the piston assembly **711**. The disc springs **782** may slightly compress when the piston assembly **711** is moved back its fully rested position.

A first pressure chamber **790** is generally defined by the sleeve **710**, the bore **704**, the enlarged end portion **760** of the piston **730**, and the seal **764**. A second pressure chamber **792**, located generally behind the enlarged end portion **760** of the piston **730**, is generally defined by the sleeve **710**, the bore **704**, the seals **752** and **764**, and the piston **730**. Passageways **794** are formed through the sleeve **710** and are in fluid communication with the second pressure chamber **792** and the conduit **650**.

There is illustrated in FIG. **7** a schematic illustration of a third embodiment of a brake system, indicated generally at **800**. The brake system **800** is similar to the brake system **600** and, therefore, like functions and structures will not be described. The brake system **10** is ideally suited for large passenger vehicles or trucks. Generally, larger vehicles require more braking power and more fluid volume than brake systems for smaller vehicles. This generally requires a larger consumption of power for the motor for the plunger assembly.

The brake system **800** includes a brake pedal unit **812**, a hydraulic control unit **814**, and wheel brakes **816***a-d*. The brake assembly **800** further includes a plunger assembly **820** having a piston **822** with a check valve **824** mounted therein. The check valve **824** permits fluid to flow from a first pressure chamber **830** to a reservoir conduit **832** (in communication with a reservoir **813**) via a conduit **834** within the piston **822**. The check valve **824** prevents the flow of fluid from the reservoir **813** to the first pressure chamber **830** via the conduit **834**. The check valve **824** also prevents the flow of fluid though the piston **882** from a second pressure chamber **836** to the first pressure chamber **830**. The system **800** includes a pumping valve **840** and a check valve **842**. The check valve **842** is located within a conduit **844**. The check valve **842** restricts the flow of fluid from the first pressure chamber **830** to the reservoir **813**, while permitting the flow of fluid from the reservoir **813** to the pumping valve **840** and first pressure chamber **830**. The pumping valve **840** is movable between an open position to permit the flow of fluid out of the first pressure chamber **830** and to a boost conduit **850** for delivering pressurized fluid to the wheel brakes **816***a-d.*

Comparing the systems **600** and **800**, the system **800** additionally includes a solenoid actuated quick fill valve **860**. The quick fill valve **860** is in fluid communication with the second pressure chamber **830** via a conduit **862**. The quick fill valve **800** is also in fluid communication with the wheel brakes **816***a* and **816***b* (such as front wheel brakes) via conduit **870**, **872**, and **874**. The conduits **872** and **874** have check valves **876** and **878**, respectively, located therein to prevent fluid from the wheel brakes flowing back into the conduit **870**. The quick fill valve **860** may have relatively large orifices that enable fluid to easily flow through the quick fill valve **860** when in its energized to its open position, such as when the plunger assembly **820** is actuated to deliver high pressure fluid to the first pressure chamber **830**. Since a lot of power may be required to force fluid through relatively small orifices in various valves and components of the system **800**, the addition of the quick fill valve **820** helps to reduce power consumption. This is especially useful for larger vehicles when the amount of fluid flow is increased compared to smaller vehicles. The quick fill valve **860** may be left energized under normal boosted braking applications. During other events, such as anti-lock braking or slip control, the quick fill valve **820** may be moved to its closed position.

There is illustrated in FIG. **8** a schematic illustration of a fourth embodiment of a brake system, indicated generally at **900**. The brake system **900** is similar in structure and function as the brake system **600**. Instead of using a single pumping valve **640**, the system **900** includes a pair of pumping valves **902** and **904** in a parallel arrangement between a second pressure chamber **910** and boost conduit **912**. It may be more cost effective to provide a pair of smaller valves than a single larger valve.

The principle and mode of operation of this invention have been explained and illustrated in its preferred embodiment. However, it must be understood that this invention may be practiced otherwise than as specifically explained and illustrated without departing from its spirit or scope.

What is claimed is:

1. A plunger assembly for use as a pressure source for a brake system, said plunger assembly comprising:

a housing having first and second ports;

a reversible motor mounted on said housing for driving an actuator;

a boost conduit for supplying fluid at a boosted pressure to the brake system;

a first outlet conduit connecting said first port to said boost conduit;

a second outlet conduit connecting said second port to said boost conduit;

a piston connected to said actuator, said piston slidably mounted within said housing and, in part, defining first and second chambers on opposite sides of said piston, wherein said piston pressurizes a-said first chamber when said piston is moving in a first direction to provide fluid out of said first port to said boost conduit, and wherein said piston pressurizes a-said second chamber when said piston is moving in a second direction opposite of said first direction to provide fluid out of said second port to said boost conduit;

an electronically controlled valve located in the first outlet conduit and switchable between a first operating mode wherein said first chamber is connected to said boost conduit to (a) enable fluid flow in both directions between said first chamber and said boost conduit and (b) enable fluid flow from said first chamber into said second chamber when said piston is moved in the first direction, and a second operating mode wherein said boost conduit is disconnected from said first chamber to prevent fluid flow from said boost conduit into said first chamber when said piston is moved in the second direction.

2. The assembly of claim **1**, wherein said plunger assembly is configured such that less torque is required by said motor to maintain the same pressure in said second chamber when said piston is moving in said second direction compared to pressure in said first chamber when said piston is moving in said first direction.

3. The assembly of claim **1**, wherein said piston includes a first portion having a greater effective hydraulic area corresponding to said first chamber than the effective hydraulic area corresponding to said second chamber.

4. The assembly of claim **1** further including a check valve mounted in said piston, said check valve restricting the flow of fluid from said second chamber to said first chamber.

5. The assembly of claim **1** further including an anti-rotation device mounted on said piston preventing rotation of said piston.

6. The assembly of claim **1** further including a hollow sleeve mounted in said housing of said plunger assembly, wherein said piston is slidably disposed in said sleeve.

7. The assembly of claim **6**, wherein said sleeve includes a tube mounted thereon, and wherein said tube is connected to said actuator.

8. The assembly of claim **1** further including a cushion member mounted on an end of said piston.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,321,444 B2
APPLICATION NO. : 13/843587
DATED : April 26, 2016
INVENTOR(S) : Blaise J. Ganzel

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

Column 20, lines 63 and 66, after “pressurizes” remove -- a- --.

Signed and Sealed this
Twenty-sixth Day of July, 2016

Michelle K. Lee
Director of the United States Patent and Trademark Office